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ADAPTIVE EEPROM STORAGE SYSTEM FOR TIRE PRESSURE LOSS DETECTION

Field of the Invention

The present invention relates to a method and an apparatus for monitoring an operating state of at least one tire of a vehicle.

Background Information

The tires of a vehicle are among the systems most critical to driving safety during operation of the vehicle. A sudden pressure decrease, which regularly occurs as an indication of tire damage, can result in limited road adhesion and, in some cases, can render the vehicle no longer controllable. At high speeds, in particular, tire pressure losses can therefore have an extremely devastating effect. Prompt detection of a defective tire can thus make a considerable contribution to driving safety.

Systems which monitor the state of a tire, in particular the air pressure, are known in the art. In addition to direct determination of the air pressure of a tire, the rotation speeds of the wheels can be employed in order to determine a change in tire pressure. For example, changes in the rotation speeds of individual wheels can be sensed and used to demonstrate a change in the operating state of the tires. Published German patent documents DE 36 10 116 and DE 32 36 520 describe monitoring systems which indicate the tire state in the context of specific operating states (traveling straight ahead without deceleration or acceleration). These documents also describe a normalization of the rotation speeds to the respective vehicle speed.

For indirect-measurement tire-pressure monitoring systems, the use of differences in wheel rotation speeds of individual wheels for tire state detection is known, for example, from European Patent 0 291 217. In such systems, pressure losses can be ascertained by way of the deviation in wheel speeds in the context of a reduced tire circumference.

Published German Patent Application 199 44 391 describes the adaptation of a calibration value serving to monitor tire pressure. In this method, a recalibration of the tire pressure system is performed on the basis of a modified operating state of the tire, the old value being overwritten.

Summary of the Invention

The present invention provides a method and an apparatus with which an operating state of at least one tire of a vehicle can be monitored. The monitored operating state may be, for example, the air pressure of the tire. Provision is further made that, one tire state variable that represents the current operating state of the tire, and one calibration variable that represents the target tire state of the tire, are taken into consideration in the monitoring. In accordance with the present invention, the monitoring is accomplished in different monitoring modes. The particular monitoring mode employed is determined as a function of at least one driving state variable representing the driving state.

In an example embodiment of the present invention, the monitoring mode is selected as a function of a comparison of the driving state variable to a definable limit value. For example, the vehicle speed can be compared to a given speed, the monitoring mode being changed if the given speed is exceeded. The present invention provides two monitoring modes, a transition from the first monitoring mode (in which the monitoring normally begins) into the second monitoring mode

taking place as a function of the comparison. In addition to the exceedance of the defined limit value, the behavior over time of the exceedance of the limit value is also monitored for the comparison. As a result of the comparison, the transition into the second monitoring mode is performed only if the exceedance of the limit value persists for a definable period of time. In a further embodiment of the invention, it is provided that no further comparison is performed after the change into the second monitoring mode has taken place. As a result, no further change in the monitoring mode is provided for.

In an example embodiment, provision is made for selecting the vehicle speed, as a differentiation criterion between the individual monitoring modes, as the driving state variable. This makes possible a monitoring process adapted to the instantaneous driving state.

In accordance with the present invention, provision is made for equipping each monitoring mode with at least one calibration mode. Provision is further made for each calibration mode to contain at least one calibration variable. It is thus possible to achieve, within the individual monitoring modes, fine gradations that permit accurate identification and monitoring of the operating state of the tire. In order to adapt the determination of the calibration variables as closely as possible to the actual operation of the vehicle, the calibration variables are determined as a function of a series of parameters. At least one tire state variable, one driving state variable, one calibration request, and/or the monitoring mode, for example, are included in the determination of the calibration variable. It is thus possible to eliminate spikes or brief disturbances from the determination by taking an average of several tire state variables in the determination of the calibration variables.

With the driving state variable, for example the vehicle speed, a calibration adapted to the modified physical behavior of the tire at high speeds, for example, can be taken into account. The calibration request moreover allows a calibration to be performed in controlled fashion when permitted by the driving situation.

In an example embodiment of the present invention, the determination of the calibration variable is performed as a function of the number of tire state variables acquired, and the monitoring mode. Provision is made in particular, in this context, for determining a calibration variable of a first kind and/or a calibration variable of a second kind, depending on the defined number of tire state variables that have entered into the determination. An example embodiment provides for the calibration variable to be determined as the average of the number of tire state variables that have entered into the determination.

In accordance with the present invention, the determination of the calibration variable of the first kind is performed until the prerequisite for creation of the calibration variable of the second kind. Provision is additionally made for further determination of the calibration variable to be terminated when the calibration variable of the second kind has been created. However, the determination of a new calibration variable may be performed again if a calibration request is identified.

The dependence of the monitoring operation on the monitoring mode represents a further example embodiment of the invention. Here, a tire state variable which represents the current tire state is determined, and is referred to the calibration variable of the monitoring mode. From the comparison, associated therewith, of the two variables, a malfunction is

identified if the difference goes outside a defined range, i.e., beyond a defined threshold value. In an example embodiment of the present invention, the defined range or the threshold value is selected as a function of at least one driving state variable, for example the vehicle speed. As a result, nonlinear or only locally linear correlations between rolling circumference and vehicle speed can also be taken into account. Alternatively or simultaneously, however, the monitoring can also be selected as a function of the number of tire state variables used for determination of the calibration variable. The advantage of this embodiment lies in the fact that the threshold values have different sensitivities as a result of the modification. A large number of tire state variables in the context of determination of the calibration variable thus reduces the variability of the tire state variables that is sensed, thereby permitting more-sensitive monitoring.

In accordance with the present invention, the monitoring of the tire state is accomplished by way of a tire state variable representing the tire state, the tire state variable being created on the basis of wheel rotation speeds. The determination of the tire state variable is ascertained by creating a difference between the wheel speeds at at least two wheels in each case. Provision is made here, in particular, for creating the difference in wheel speeds at the wheels of one axle and/or at the diagonally located wheels. In addition to this, however, the possibility also exists of determining the tire state variable by creating a difference between the sums of the wheel rotation speeds at the wheels of the front axle and of the rear axle. It is also possible, however, to determine the tire state variable as the difference between the sums of the wheel rotation speeds at the wheels of the left and of the right side of the vehicle. In a further embodiment, provision is moreover made for normalizing the

created differences to the vehicle speed. Provision is furthermore made for ascertaining the wheel rotation speed by way of a wheel dynamics variable representing the wheel rotation speed.

In accordance with the present invention, the calibration request may be accomplished at a defined point in time. The point in time can be determined by way of a command initiated by the driver, or automatically by detecting a tire change or an operation of adding air to the tire.

The present invention may provide that upon detection of a malfunction, i.e., upon occurrence of a pressure loss in a tire, the driver is informed thereof acoustically and/or optically. It is furthermore possible, upon detection of a malfunction, to activate a braking system present in the vehicle and/or an active steering system, in such a way that the vehicle's reaction counteracts the cause of the malfunction. Dangerous driving situations resulting from a pressure loss in the tires can thus be compensated for or mitigated.

In a further example embodiment of the invention, the fact that the definable limit value has been exceeded by the driving state variable during a defined time is interpreted as a prerequisite for a tire state in which a plastic deformation of the tire is occurring.

Brief Description of the Drawings

Figure 1 shows, in a block diagram, the acquisition of operating variables that are necessary for monitoring of the tire state, and the processing of the read-in values and forwarding of a detected malfunction.

Figure 2 depicts in a flow-chart the initialization and

determination of the calibration variables.

Figure 3 depicts in a flow-chart the sequence of monitoring the tire air pressure.

Figure 4 depicts in a flow-chart the procedure of a further exemplary embodiment of the present invention.

Figure 5 depicts in a flow-chart the operation of monitoring attainment of a high-speed range.

Detailed Description

Figure 1 shows an exemplary embodiment for monitoring of a vehicle having four tires. An adaptation of the example to a vehicle having additional tires is certainly possible, but not necessary for presentation of the example. For acquisition of the monitoring parameters necessary for monitoring, each wheel equipped with a tire possesses a wheel rotation speed sensor (130 through 136) for ascertaining the wheel rotation speed. From these wheel rotation speed sensors (130 through 136), the wheel rotation speed variables v_{VR} (140), v_{VL} (142), v_{HR} (144), and v_{HL} (146), which represent the wheel rotation speeds, are forwarded to central monitoring unit 100. To complete the driving-dynamics variables for monitoring, monitoring unit 100 reads out of a corresponding system 138 a variable v_{car} (148) representing the vehicle speed. In block 150, tire state variables Δv_A, Δv_D which represent the tire state of the wheels are ascertained from these read-in values.

An initialization, which can be accomplished manually by the driver and/or automatically, for example by a calibration request generator 110, in the context of a tire change or an operation adding air to the tire, causes a flag F_I (115) to be set, i.e., flag F_I changes from the value 0 to the value 1. A further exemplified embodiment shows, however, that in

addition to continuous setting of the flag, a brief setting of flag F_I (115) is sufficient for initialization of the calibration operation.

In block 150, because flag F_I (115) is set, calibration values are created from the tire state variables as a function of the read-in vehicle speed variable v_{car} (148). Only wheel speed variables (140 through 146) that are suitable for the purpose are used, however, to ascertain the tire state variables. Certain driving situations are conceivable - for example heavy braking/acceleration, cornering, or an ABSR/ESP control action - that do not supply tire state variables suitable for evaluation. To filter such driving situations out of the monitoring process and the determination of calibration variables, a driving observation module 120 is used; this detects the corresponding driving situations and sets a flag F_M (125) if monitoring and calibration are to be briefly discontinued.

Since the tires have different physical properties depending on the rotational velocity of the wheel, various speed ranges are set up. This can be done, for example, using the index B as shown in the following table:

Index B	Speed Range V_B [km/h]
1	0-50
2	51-100
3	101-150
4	151-200
5	201-250

However, other subdivisions adapted to the particular vehicle are also conceivable. It is furthermore possible to make the

speed ranges variable during operation of the vehicle.

Since the behavior of the tires also changes along with the tire properties, it is necessary to ascertain separate calibration variables for each speed range. In the context of monitoring the operating state of the tires, the vehicle speed variable v_{car} (148) is therefore employed in order to allocate the corresponding calibration variable.

The calibration variables ascertained in the individual speed ranges, as well as the number n of tire state variables taken into account in that context, are stored in a memory 155 and read out as necessary. If a malfunction is identified in the course of the monitoring, the driver can be informed thereof. This can be accomplished both optically and acoustically via a corresponding indicator 170. It is also conceivable, on the basis of the detected malfunction, for a system 190 located in the vehicle, which counteracts the possible impairments of driving behavior resulting from the tire pressure loss by way of a corresponding control action 180, to be activated. Present-day systems that can perform this are, for example, an ABS, ESP, or an active steering system.

The flow chart in Figure 2 describes one possible program sequence for ascertaining the calibration variables that are required as reference values for monitoring the tire state, e.g., the tire air pressure. In a first step 200 the calibration request is queried. This is done by querying flag F_I (115). If an unset flag F_I (115) is detected, i.e., $F_I = 0$, the program terminates execution. If, however, a set flag F_I (115) (i.e., $F_I = 1$) indicates that a calibration request has been made by the driver or on the basis of automatic detection, then in the next step 205 the flags F_{KB}, which represent a successful determination of a calibration variable for speed range V_B by way of a set flag $F_{KB} = 1$, are set to a

value of 0 for all indices B. In step 210, execution pass variable n_B and calibration variables Kal_{AB} for single-axle monitoring and Kal_{DB} for diagonal monitoring are also set to 0 for all indices B. For determination of the current speed range V_B, in step 215 vehicle speed variable v_{car} (148), representing the vehicle speed, is read in. A comparison of vehicle speed variable v_{car} (148) to the previously subdivided speed ranges V_B allows a determination of the range in which the vehicle is located. This comparison yields the associated value of index B that is used for further determination of the calibration variable. If it is found by way of execution pass variable n_B that the current execution pass for ascertaining the calibration variable is the first one, i.e., if $n_B = 0$, the value of index B belonging to the current speed range V_B is then stored in a variable Z_K. This allows identification of the calibration variable that has been determined, and allocation thereof to the associated speed range. Step 220 then checks whether the current speed range V_B matches the range in which the calibration is to be performed. This is done by comparing the value of B determined in step 215 to the variable Z_K. This comparison thus allows identification of a switchover into a different speed range brought about by a change in vehicle speed v_{car} (148). At the same time, the existence of an already determined calibration variable of the second kind for speed range V_B is queried by way of flag KB. As already described, a set flag $F_{KB} = 1$ indicates the presence of a calibration variable of the second kind in the corresponding speed range V_B. If the decision upon combination of the two comparisons

$$B = Z_K$$

and

$$F_{KB} = 0$$

is negative, then in step 225 the allocation

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$$Z_K = B$$

is made, in order to adapt variable Z_K to the current speed range with the value of index B. After this allocation in step 225, step 210 starts a new cycle for determining the calibration variable. In the event of a positive outcome of the comparison in step 220, the program proceeds with the next step 230. Here the wheel rotation speeds v_{VR} (140), v_{VL} (142), v_{HR} (144) and v_{HL} (146) are read in. If the vehicle is in a driving situation that does not permit determination of a tire state variable suitable for evaluation, flag F_M (125) is then set, i.e., $F_M = 1$. Because this flag F_M (125) is set, in step 235 execution branches to step 240 of the flow chart, in which the allocation

$$Z_K = B$$

is made in order to adapt variable Z_K to the current speed range of index B. Once the allocation $Z_K = B$ has been made in step 240, the program loops back to step 215.

If an impermissible driving situation was not identified, however, i.e., if $F_M = 0$, then in step 245 the equations

$$\Delta v_A := \{(v_{VL} + v_{VR}) - (v_{HL} + v_{HR})\} / v_{car} \cdot$$
$$\Delta v_D := \{(v_{VL} + v_{HR}) - (v_{VR} + v_{HL})\} / v_{car}$$

are used to ascertain the wheel state variables, which are determined on both a single-axle (Δv_A) and diagonal basis (Δv_D) for wheel rotation speed variables v_{VR} (140), v_{VL} (142), v_{HR} (144), and v_{HL} (146), normalized to the vehicle speed v_{car} (148). Also in step 245, the execution pass variable n_B is incremented:

$n_B = n_B + 1$.

The wheel state variables Δv_A and Δv_D ascertained in this fashion are then used, in step 250, to ascertain calibration variables Kal_{AB} and Kal_{DB}, using

$$Kal_{AB} = Kal_{AB} + \frac{Kal_{AB} - \Delta v_{AB}}{n_B}$$

and

$$Kal_{DB} = Kal_{DB} + \frac{Kal_{DB} - \Delta v_{AB}}{n_B}$$

In order to define a calibration variable of the first kind, in step 255 a minimum number n_{min} is defined which must be reached or exceeded by execution pass variable n_B in order to reach step 260. If, on the other hand, at this point in time fewer tire state variables than the required number have entered into the determination of the calibration variable of the first kind, the algorithm is then continued with step 240. In addition to a minimum number n_{min} for all speed ranges V_B, in another example embodiment it is also conceivable to define, using $n_{min,B}$, a separate minimum number for each individual speed range V_B.

If it is found in step 255 that a sufficient number of tire state variables have entered into the determination of the calibration variable of the first kind, in step 260 calibration variables Kal_{AB} and Kal_{DB} are stored in memory 155. For determination of a calibration variable of the second kind, step 265 checks, by a comparison to execution pass variable n_B , whether the maximum number n_{max} of tire state variables that have entered into the determination of the

calibration variable has been reached or exceeded. By analogy with the comment regarding minimum number n_{min}, an example embodiment is also possible for maximum number n_{max} in which, using $n_{max,B}$, a separate maximum number can be defined for each individual speed range V_B. The values according to the table below can be used as an example for the minimum and maximum numbers n_{min} and n_{max}:

n_{min}	n_{max}
250	5000

If the result of the check in step 265 is negative, i.e., if fewer tire state variables than the maximum number have been used for ascertaining the calibration variable, the algorithm is then continued in step 240. If, however, it is found in step 265 that a sufficient number of tire state variables ($n_B \geq n_{max}$) have entered into the determination of the calibration variable, this calibration variable of the second kind then constitutes the comparison variable for the corresponding speed range V_B until the next identification of a calibration request $F_I = 1$. In the comparison to the calibration variable of the first kind, the calibration variable is no longer modified in a further execution pass without a calibration request. This is indicated by the fact that in step 270, flag F_{KB} belonging to the corresponding speed range V_B is set, i.e., $F_{KB} = 1$. Step 275 then queries whether one of the flags F_{KB} for all indices B is still unset. Since this would indicate a missing calibration variable of the second kind, a positive decision in step 275 moves execution to step 240 for further processing. If, however, flags F_{KB} are set for all indices B, then in step 280 flag F_I (155) is deleted, i.e., reset $F_I = 0$. This reset is forwarded to block

110 in order to make possible another calibration request by the driver or on the basis of automatic detection. The program is then terminated, before being restarted either at regular time intervals or on the basis of a calibration request.

One possible algorithm for monitoring tire states, e.g., tire air pressures, is depicted with reference to a flow chart in Figure 3. Once the algorithm has been started, in step 300 flag F_M (125) is queried. If it is found here that flag F_M (125) is set, i.e., $F_M = 1$, meaning the vehicle is in a driving situation that is unsuitable for evaluation of a tire state variable, the algorithm is immediately terminated. If an unset flag F_M (125) is found, however, then in step 310 the vehicle speed variable v_{car} (148) representing the vehicle speed is read in. By comparing vehicle speed variable v_{car} (148) to the previously subdivided speed ranges V_B, it is possible to determine the range in which the vehicle is currently located. This comparison yields the associated value of index B, which defines the monitoring range and is used for further monitoring. In the next step 320, calibration variables Kal_{AB} and Kal_{DB} and execution pass variable n_B, in addition to wheel rotation speed variables v_{VR} (140), v_{VL} (142), v_{HR} (144) and v_{HL} (146), are read out of memory 155. The check as to whether calibration variables exist in the current speed range V_B is then performed in step 330. The existence of the calibration variables for speed range V_B can be queried explicitly, for example, by making the comparisons

$$Kal_{DB} \neq 0$$

and

$$Kal_{DB} \neq 0$$

If both calibration variables have a value of 0, the algorithm is terminated until the next start instruction. If the

comparison in step 330 is positive, however, then in step 340 the single-axle Δv_A and diagonal Δv_D tire state variables are ascertained using

$$\Delta v_A := \{(v_{VL} + v_{VR}) - (v_{HL} + v_{HR})\} / v_{car} \cdot$$
$$\Delta v_D := \{(v_{VL} + v_{HR}) - (v_{VR} + v_{HL})\} / v_{car}$$

based on wheel rotation speed variables v_{VR} (140), v_{VL} (142), v_{HR} (144) and v_{HL} (146) determined in step 320 and normalized to vehicle speed v_{car} (148). If however, only one calibration variable Kal_{AB} or Kal_{DB} is set to 0 in step 330, the associated tire state variable is not determined.

Before the calibration variables are compared to the tire state variables that have been ascertained, the permissible defined threshold values SW_{AB} and SW_{DB} must be adapted to the number of tire state variables serving as basis for the calibration variable. More specifically, the less sensitive (i.e. higher) threshold values must be, the smaller the number of tire state variables serving as basis for the calibration variables. In the present example embodiment, therefore, in step 350 the threshold values are ascertained as a function of the number n_B of tire state variables that have entered into the calibration. Using the equations

$$SW_{AB} = SW_{AB} * (1+SW_F)$$

and

$$SW_{DB} = SW_{DB} * (1+SW_F)$$

for example, the threshold values can be modified by the factor SW_F as a function of the number n_B. One possible allocation of the modification factor in relation to the

number n_B is shown by the following table:

$n_B \geq$	Factor SW_F
250	1/10
500	5/100
1000	2/100
2000	1/100
3300	3/500
5000	1/500

For example, a number $2000 > n_B > 1000$ means a modification of the threshold values by a factor of 1.02. For finer gradations, it is possible to select additional subdivisions or an entirely different allocation. The dependence of the threshold value on the number of tire state variables included in the determination of the calibration variable is not, however, the only conceivable dependence. In a further example embodiment, the threshold values are modified as a function of the vehicle speed v_{car} (148) and the speed range V_B.

The threshold values SW_{AB} and SW_{DB} ascertained in step 350 are then used in step 360 to determine the deviation of the ascertained tire state variables Δv_A or Δv_D from calibration variables Kal_{AB} and Kal_{DB}. This is done by checking whether the equations

$$|Kal_{AB} - \Delta v_{AB}| < SW_{AB}$$
$$or$$
$$|Kal_{DB} - \Delta v_{DB}| < SW_{DB}$$

are satisfied. If so, the algorithm is terminated with no

further consequences. If one of the deviations goes beyond the threshold value, the wheel that is exhibiting a tire pressure loss can be deduced in step 370, based on a synopsis of the deviations. In step 380, the algorithm completes the monitoring cycle with an error message 160 to an acoustic and/or optical indicator 170 which informs the driver of the tire pressure loss, and a suitable activation 180 of a system 190 for compensating for the threat of a loss of driving stability.

In addition to the monitoring of tire pressure in speed ranges using incompletely performed calibration values, a further example embodiment of the present invention may utilize extrapolation of calibration values for those speed ranges for which a complete calibration has not yet been performed. To achieve this, in the program sequence shown in Figure 3, after wheel rotation speed variables v_{VR} (140), v_{VL} (142), v_{HR} (144) and v_{HL} (146) as well as calibration variables Kal_{AB} and Kal_{DB} and execution pass variable n_B have been read in from memory 155, a further program section illustrated in Figure 4 is executed. In this program section, step 400 first checks, using $F_{KB} = 1$, whether a complete calibration has been performed, and a corresponding calibration value Kal_{AB} or Kal_{DB} exists, in the current speed range B in which the vehicle is located. If it is found that a complete calibration has already been accomplished, program execution continues with step 330 in Figure 3. If a complete calibration has not yet been performed, however, step 410 then checks, with $F_{K(B-1)} = 1$, whether a calibration value from a complete calibration is available for speed range B-1 located below speed range B. If so, a calibration data set Kal_{AB} and Kal_{DB} for speed range B is extrapolated from calibration data set $Kal_{A(B-1)}$ and $Kal_{D(B-1)}$ for speed range B-1. This is done by first, in step 420, creating the difference between the current vehicle speed v_{car} (148) and the maximum limit speed for speed range B-1, using:

$$\Delta v = |v_{car} - \text{max. limit speed of range } B\text{-}1|$$

Δv being an indication of the deviation of the current vehicle speed v_{car} (148) from the next-lower speed range. As a function of this deviation and in conjunction with the calibration values from speed range B-1, calibration values for speed range B are generated using

$$Kal_B = f(Kal_{B-1}, \Delta v).$$

One possible allocation of the calibration values can be made using

$$Kal_{AB} = Kal_{A(B-1)} * (1+Kal_F)$$

and

$$Kal_{DB} = Kal_{D(B-1)} * (1+Kal_F);$$

the modification of the calibration variables Kal_F as a function of Δv can be performed, for example, in accordance with the following table:

Deviation (km/h)	Factor Kal_F
$0<\Delta v\leq 5$	2/100
$5<\Delta v\leq 10$	5/100
$10<\Delta v\leq 20$	1/00
$20<\Delta v\leq 30$	2/10
$30<\Delta v\leq 40$	5/10

If it is found in step 410 that a complete calibration has not been performed in speed range B-1, then in step 440 a corresponding query is made for speed range B+1. If flag $F_{K(B+1)}$

is not set, the monitoring is discontinued. If, however, $F_{K(B+1)} = 1$ indicates detection of a complete calibration in speed range B+1, then in accordance with the procedure in steps 420 and 430, the deviation of the current vehicle speed v_{car} (148) from the next-higher speed range B+1 is ascertained in step 450 using

$$\Delta v = |v_{car} - \text{min. limit speed of range B+1}|.$$

This is followed in step 460 by an extrapolation of the calibration values for speed range B using

$$Kal_B = f(Kal_{B+1}, \Delta v).$$

As explained above in connection with step 430, one possible allocation of the calibration values involves the use of

$$Kal_{AB} = Kal_{A(B+1)} * (1+Kal_F)$$

and

$$Kal_{DB} = Kal_{D(B+1)} * (1+Kal_F).$$

The modifications of the calibration variable Kal_F can be performed in accordance with the table presented above.

Step 470 then checks for the existence of calibration variables in the calibration data set of the current speed range V_B. If both calibration variables have the value 0, the algorithm is terminated until the next start instruction. If the result of the comparison in step 470 is positive, however, then in step 480 the single-axle tire state variable Δv_A and diagonal tire state variable Δv_D are ascertained, similarly to step 340, using

$$\Delta v_A := \{(v_{VL} + v_{VR}) - (v_{HL} + v_{HR})\} / v_{car} \cdot$$
$$\Delta v_D := \{(v_{VL} + v_{HR}) - (v_{VR} + v_{HL})\} / v_{car}$$

based on wheel rotation speed variables v_{VR} (140), v_{VL} (142), v_{HR} (144) and v_{HL} (146) determined in step 320 and normalized to vehicle speed v_{car} (148). If, however, in step 470 a calibration variable Kal_{AB} or Kal_{DB} is set to 0, the associated tire state variable is not ascertained.

In the context of monitoring using extrapolated calibration variables, an adaptive adaptation of the threshold values as a function of the speed deviation Δv can additionally be performed, as shown in step 490. For example, using

$$SW_{AB} = SW_{AB} * (1+SW_F)$$

and

$$SW_{DB} = SW_{DB} * (1+SW_F),$$

the corresponding threshold values can be assigned a correction factor SW_F that can be selected as a function of Δv. The table below represents one possible allocation:

Deviation km/h	Factor SW_F
$0<\Delta v\leq 5$	2/100
$5<\Delta v\leq 10$	5/100
$10<\Delta v\leq 20$	1/00
$20<\Delta v\leq 30$	2/10
$30<\Delta v\leq 40$	5/10

Once the modified threshold values for the extrapolated

calibration variables have been ascertained, monitoring is continued with step 360 as depicted in Figure 3.

Figure 5 depicts a further example embodiment in which exceedance of a limit value by a driving state variable indicates a change in a monitoring mode. The change in monitoring mode generates a calibration request (115) and, optionally, the algorithm described in Figure 2 is started immediately thereafter.

In the example embodiment shown in Figure 5, step 500 first queries whether a high-speed range has already been attained at earlier points in time during vehicle operation. This can be determined, for example, if a flag F_H is set, i.e., $F_H = 1$. If a set flag F_H is detected, the algorithm shown in Figure 5 is terminated. Otherwise, in step 510, limit values SW_G and SW_t are read in from memory 155. Limit value SW_G represents a vehicle speed value that, when exceeded the first time by a new tire, results in an irreversible one-time plastic deformation (spreading) of the tire. In order for a deformation of the tire to be observed, however, the tire must be driven for a defined time SW_t above vehicle speed SW_G. Both variables are specific to the tire, and can be updated in memory 155, for example, by way of an external update or an automatic detection of the tire or of a tire change. In addition to the reading in of values SW_G and SW_t, an internal timer is started (t = 0) in step 510. In the next step 520, the instantaneous vehicle speed v_{car} (148) is read in. In step 530 this instantaneous vehicle speed v_{car} (148) is compared to limit value SW_G. If the instantaneous vehicle speed v_{car} (148) is below limit value SW_G, the algorithm is terminated. If v_{car} (148) exceeds SW_G, however, then in step 540 the behavior over time of the exceedance is checked. If it is found that the tire has not yet been driven for sufficient time at the corresponding speed, the algorithm continues to execute with

step 520. If, however, the tire has been operated for a defined time above the stipulated speed limit value SW_G, i.e., if the comparison $t > SW_t$ gave a positive result, then in step 550 flags F_H and F_I (115) are set, and are stored in memory 155. A set flag $F_H = 1$ indicates that the tires have experienced a plastic deformation. A set flag $F_I = 1$ moreover makes possible a restart of the calibration algorithm that was presented in a previous exemplified embodiment. Optionally, in step 560, subsequent to step 550, initiation of the calibration algorithm (e.g., in accordance with the example embodiment of Figure 2) can then also be enabled before the algorithm shown in Figure 5 is complete.

The case of a single new tire plays a critical role in the consideration of the irreversible one-time plastic deformation of new tires when a speed threshold is exceeded. If, for example, a spare tire is mounted on a vehicle that already has three previously broken-in tires, the calibration operation must be restarted, since otherwise the deformation of the new tire after exceedance of the speed threshold value would cause the spare tire to roll more slowly. The calibration operation can be restarted on the one hand manually by the driver of the vehicle, but also automatically by resetting flag F_I, i.e., $F_I = 0$. This can be done, for example, by manual deletion of flag F_I (115) by the mechanic or the driver upon replacement of the tire. Another possibility is that replacement of a tire is detected automatically and causes a reset of flag F_I (115).

The algorithms presented in the example embodiments set forth above can be started for monitoring at regular intervals, or on the basis of a deliberate action by the driver.